SUSTAINABLE DESIGN OF A MULTI-STORY BUILDING USING WASTE MARBLE AND CERAMIC

[a] ***Muhammad Haroon Kabir**, [b] *Anwar Khitab***

a: Department of Civil Engineering, MUST, Mirpur, Pakistan. muhammadharoonkabir42@gmail.com
b: Department of Civil Engineering, MUST, Mirpur, Pakistan. Anwar.ce@must.edu.pk
* Corresponding author

Abstract- This project deals with the design of a High-rise building by using waste materials. The locally developed building materials from recycled wastes were used in manufacturing concrete and bricks. A ten-story high-rise building was designed using the software ETABS. The concrete comprised of 10% partial replacement of cement by waste marble powder (WMP) and the bricks contained 12% waste ceramic powder and 15% waste brick powder as replacement of clay. These materials were developed in the lab, and their properties were determined as per ASTM standards. The characteristics were incorporated in the software and the building was designed and analyzed. The designed building was compared with that containing conventional concrete and bricks. It was found that the design having waste materials resulted in the saving of 164 tons of cement, and 475 m3of fertile clay, while meeting the stability standards as documented in the building codes. The design prevents the emission of 148 tons of carbon into the atmosphere and significantly saves energy required for cement manufacturing. Additionally, the building incorporating waste materials costs Rs. 5.8 million less than one made with conventional materials.

Keywords- High-rise Buildings, Recycling, Waste Marble, Waste ceramic, Environmental Impact, Cost effectiveness.

1 Introduction

In today's modern world, concrete is widely used in the construction of civil engineering structures. Concrete comprises of three main constituents: cement, sand, and coarse aggregate. The production of cement produces a huge amount of carbon dioxide and contributes significantly to global warming. Its manufacturing requires a temperature of 1400 ºC, which is achieved by burning fossil fuels [1]. Thus, it also causes the depletion of fossil fuels. It is necessary to reduce the use of cement to make the construction sustainable and eco-friendly.

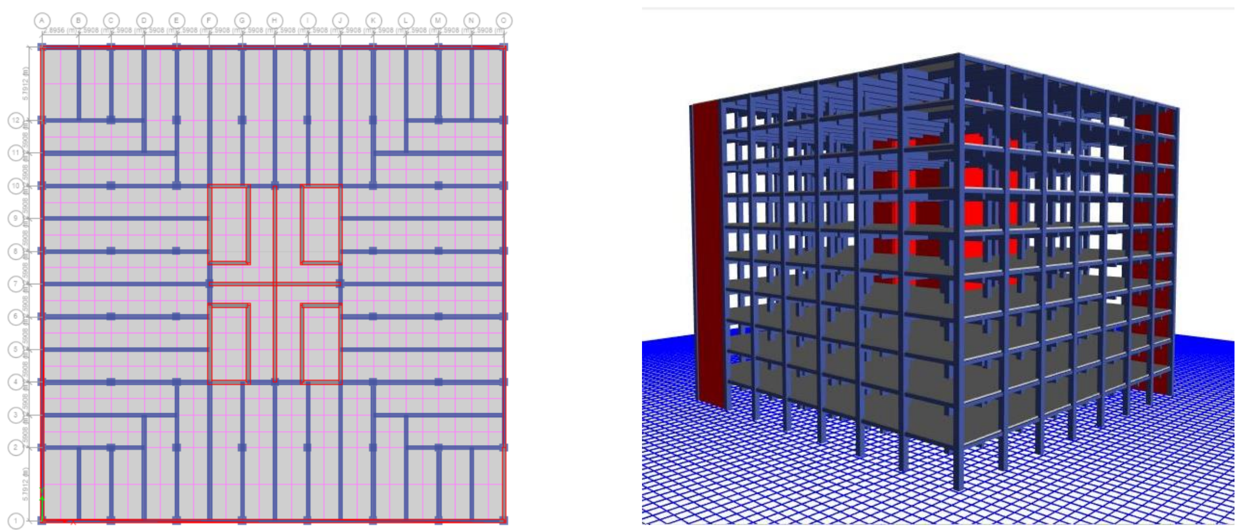
Marble is one of the most important and widely used stones. It is calcareous in nature and is the metamorphic form of limestone. Majeed et al. studied the effect of waste marble powder (WMP) on the properties of concrete. The results showed that up to 10% replacement of WMP, the compressive and tensile strengths of concrete are improved. The increase in mechanical strength was attributed to the pozzolanic and cementing characteristics of the Marble [2]. Memon et al. studied the effect of partial replacement of marble dust with cement on the fresh and hardened properties of concrete. The results showed greater compressive strength in concrete and a decline in workability [3]. Özkılıç et al. examined the effect of marble powder on the performance of concrete. The authors partially replaced cement with 10-40 % of waste marble powder. The authors recommended a dosage of 10% waste marble powder as a partial replacement cement, based on the mechanical and sustainability aspects [4]. Khitab et al. examined the effect of waste brick powder (WBP) and waste ceramic powder (WCP) as replacements for clay in bricks. The study found that incorporating 15% WBP and 12% WCP resulted in the same density as with 100% clay [5]. An increased brick porosity was also obtained as compared to clay bricks, making them suitable for moderate weather resistance and insulation. Moreover, compressive strength reduced with 15% WBP and 12% WCP addition but remained adequate for second-class bricks. There was a 27% decrease in the initial water absorption rate in bricks with the replacement. Additionally, there was no efflorescence in the bricks. The incorporation of WBP in the production of clayey bricks saved 27% of fertile clay, leading to environmentally friendly construction [5].

This work deals with the design and analysis of an RCC high-rise building. In the design, concrete containing 10% WMP as a partial replacement of cement was used. Additionally, partition walls of red bricks were provided, in which 27% fertile clay was replaced by a mixture of 10% WCP and 12% WBP. The aim was to design a sustainable building based on the materials previously developed in our research group. The benefits of using locally developed materials were assessed by designing an actual RCC structure and comparing it with the conventional building in terms of environmental impact and cost. This work aims to provide the benefits of a green building in terms of waste reduction and utilization in accordance with the sustainable development goals of UNO [6]. A 10-story building was chosen as a test case. The design and analysis were carried out using ETABS. The benefits of green building are presented in the form of reduction in greenhouse gas emission, the use of natural resources, energy and cost.

2 Research Methodology

2.1 Dimensions of the proposed building:

The proposed plan for the high-raise building is shown in Figure 1. It has dimensions of 37m x 36.57m with a height of 32m including ground floor. In this design, 4 shear walls were provided as per recommendations of ASCE 7-17 [7].



a) b)

Figure 1: Two- & Three-Dimensional Plan of proposed model

The shear walls are highlighted with red ink in Figure 2. One shear wall each was provided along the longer side and two central shear walls were provided in the middle along the shorter side. The building was subjected to dead, live, wind and earthquake as per Universal Building Codes 97 [8].

2.2 Design & Analysis:

The proposed building was modeled using ETABS, and properties of the materials resulting from past research were assigned to the components of the building, i.e., slabs, columns, beams, walls, etc. The material properties used in the design are shown in Table 1. These properties were acquired from our previous researches [5], [9].

Table 1 Properties of materials used [5], [9]

Materials	Compressive Strength (MPa)	Density (kg/m^3)	Poisson's Ratio	Modulus of Elasticity (GPa)
Conventional concrete	25	2385	0.2	23.5
10% WMP in Concrete	32	2410	0.2	26.6
Conventional brick	9.31	2162	0.2	12.4
15% WBP + 12% WCP in Bricks	9	1400	0.2	14.1

3 Results

After designing the model in ETABS, dimensions of the components of green building (i.e. slabs, beams, columns and walls) for all stories are shown in table 2.

Table 2 Dimensions obtained from design

Components	Width (mm)	Depth (mm)
Slabs	-	175
Beams	300	750
	300	300
Columns	560	560
Shear Walls	300	-
Perimeter Walls	228	-

After analyzing the model, the parameters were checked by the given ACI code (i.e. ACI-318-14) [10] using ETABS, which indicated that the building was stable. Some significant limit state parameters are provided in Table 3.

Table 3 Analysis Parameters

Display Type	Load	Max. (X-direction)	Max. (Y-direction)	Max. Limit
Story Drift (Unit less)	Earthquake	0.000141	0.0000136	0.0015
Max. story Displacement (mm)	Earthquake	3.63	3.66	30
Overturning Moments (KN-m)	Earthquake	558434	-480000	Depends on foundation soil

Story drift is a parameter, which shows the relative displacement of a floor with respect to the next floor. According to Indian Standards IS 1893 (Part 1) [11], the maximum story drift should be less than 0.004, whereas the Appendix C of ASCE 7 put a limit ranging from 0.005 to 0.0015 [7]. The story displacements are well within the limits[12]. The comparison of different parameters that are linked with sustainability are given in Table 4:

Table 4: Sustainability Parameters

Parameters	Conventional Building	Green Building	Savings	Cost Effectiveness (Millions of Rs.)
Cement (tons)	1088	924	164	4.75
Carbon Dioxide (tons) [13]	979	813	148	-
Electricity (kWh)[14]	119704	101597	18167	0.73
Clay (m^3)	1762	1287	475	0.332
Structure weight (MN)	169.22	141.8	27.4	-
			Total saving in Rs. Million	**5.812**

The use of green materials, which have been tested in the labs, is an eco-friendly approach: this not only provides saving in cement, but also in the associated greenhouse gas emissions. The energy requirements can be reduced owing to lesser manufacturing of cement. Additionally, the incorporation of 27% waste in bricks results in a significant reduction of fertile clay, which can be preserved for crops, vegetables and fruit.

4 Conclusions

This work deals with the design of a 10-story RCC building using green materials, developed in the lab. Based upon the simulations, the following conclusions are withdrawn:

1. The designed building provides a saving of 164 tons of cement, and 475 m^3 of fertile clay.
2. The saving in cement corresponds to a reduction of 513 tons of CO_2 to the atmosphere, and an energy conservation of 18.2 MWh.
3. The proposed green design assures a cost reduction of 5.8 million PKRs.
4. The building incorporating waste materials is 16% lighter than that containing conventional materials.

References

[1] A. Khitab and W. Anwar, "Classical Building Materials," 2016, pp. 1–27.
[2] M. Majeed, "Evaluation of Concrete with Partial Replacement of Cement by Waste Marble Powder," *Civ. Eng. J.*, vol. 7, p. 13, 2021.
[3] F. A. Memon, "Effect of Marble Dust as a Partial Replacement of Cement on Fresh and Hardened Properties of Concrete," in *International conference on sustainable development in civil engineering*, 2017, p. 6.
[4] Y. O. Özkılıç *et al.*, "Optimum usage of waste marble powder to reduce use of cement toward eco-friendly concrete," *J. Mater. Res. Technol.*, vol. 25, pp. 4799–4819, Jul. 2023.
[5] A. Khitab *et al.*, "Manufacturing of Clayey Bricks by Synergistic Use of Waste Brick and Ceramic Powders as Partial Replacement of Clay," *Sustainability*, vol. 13, no. 18, p. 10214, Sep. 2021.
[6] United Nations, "The Sustainable Development Goals Report 2020," 300 East 42nd Street, New York, NY, 10017, United States of America., 2020.
[7] ASCE/SEI 7-17, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. Reston, VA: American Society of Civil Engineers, 2017.
[8] International Code Council, *1997 Uniform Building Code*, First. United States of America: International Conference of Building Officials, 1997.
[9] M. Majeed, A. Khitab, W. Anwar, R. B. N. Khan, A. Jalil, and Z. Tariq, "Evaluation of concrete with partial replacement of cement by waste marble powder," *Civ. Eng. J.*, vol. 7, no. 1, 2021.
[10] ACI CODE-318-14, *Building Code Requirements for Structural Concrete and Commentary*. United States of America: American Concrete Institute, 2014.
[11] S. Gawande *et al.*, "Seismic Analysis of Tall Structures," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 822, no. 1, p. 012028, Jul. 2021.
[12] B. Burak and H. G. Comlekoglu, "Effect of Shear Wall Area to Floor Area Ratio on the Seismic Behavior of Reinforced Concrete Buildings," *J. Struct. Eng.*, vol. 139, no. 11, pp. 1928–1937, Nov. 2013.
[13] O. E. Ige, D. V. Von Kallon, and D. Desai, "Carbon emissions mitigation methods for cement industry using a systems dynamics model," *Clean Technol. Environ. Policy*, vol. 26, no. 3, pp. 579–597, Mar. 2024.
[14] M. R. Karim, M. F. M. Zain, M. Jamil, F. C. Lai, and M. N. Islam, "Use of Wastes in Construction Industries as an Energy Saving Approach," *Energy Procedia*, vol. 12, pp. 915–919, 2011.